Comparison of the magnetic field strength between frusta and cuboidal permanent magnets

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Introduction

Cuboidal permanent magnets have been studied extensively, with the first three-dimensional field and force equations being derived in 1984 [1]. In addition, cuboids are simple to manufacture and therefore see wide use in industry. However, numerous studies have indicated that alternative magnet geometries may produce more desirable magnetic fields than cuboidal magnets.

This concept has been explored by several authors examining planar Halbach arrays by incorporating triangular prismatic magnets in addition to cuboidal magnets. However, no research has been conducted on using frustum magnets in planar arrays. Presented here is an investigation into potential advantages in planar Halbach arrays using frustum magnets rather than cuboidal magnets.

Motivation

Consider the symmetric pyramid frustum permanent magnet shown in Figure 1. It has magnetisation in the z-direction, a height of h units, and a wall angle of θ. The magnetic field it produces can be calculated by solving the associated polyhedral magnet field equations published by several authors [2,3].

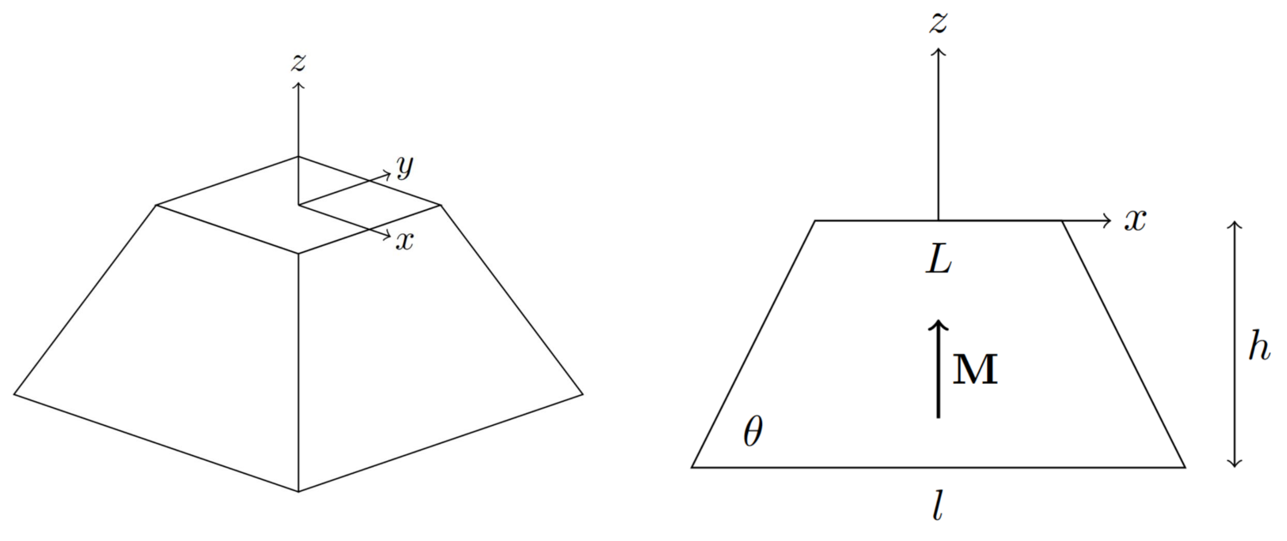

Figure 1: A frustum permanent magnet with magnetisation in the z-direction.

The magnetic field in the z-direction was calculated across the XZ plane and is plotted as a contour plot in Figure 2. As a comparison, the field along the XZ plane of an equivalent cube magnet with the same height and volume was also calculated, and is plotted alongside the field produced by the frustum.

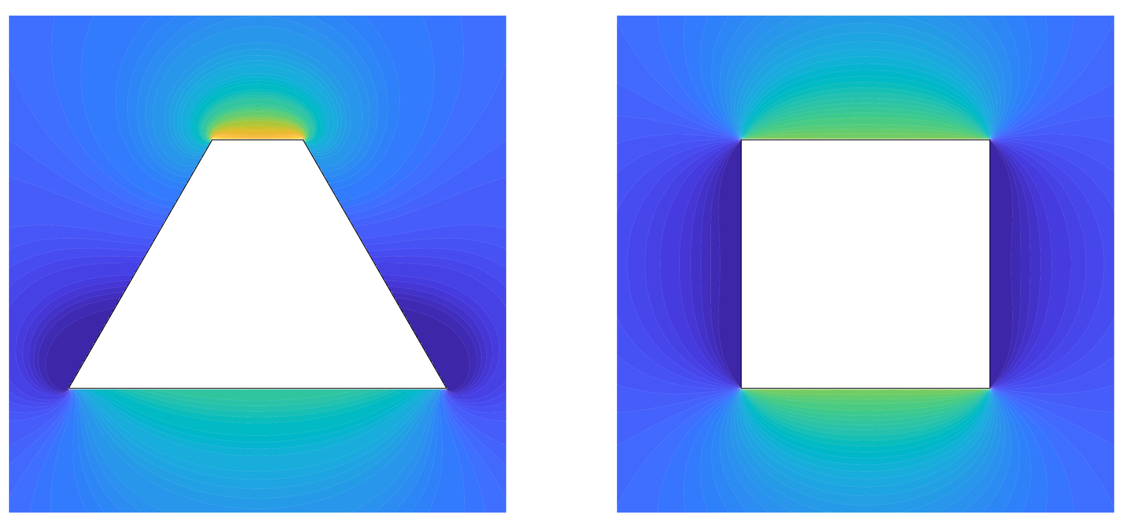

Figure 2: The magnetic field in the z-direction measured across the XZ plane of both a frustum and cube permanent magnet.

Figure 2 suggests that a frustum is able to focus magnetic flux through the smaller parallel face, thus producing more flux over a smaller area above the magnet. However, the larger parallel face distributes the flux over a larger space, resulting in weaker flux across a larger area below the magnet. This disparity suggests that the magnetic field produced by a planar Halbach array can be manipulated using frustum magnets rather than cuboidal magnets.

Optimising the field produced by a planar Halbach frustum magnet array

Frustum permanent magnets can be tesselated using frusta of pyramids and tetrahedra, and can be adapted to a two-dimensional Halbach array as shown in Figure 3.

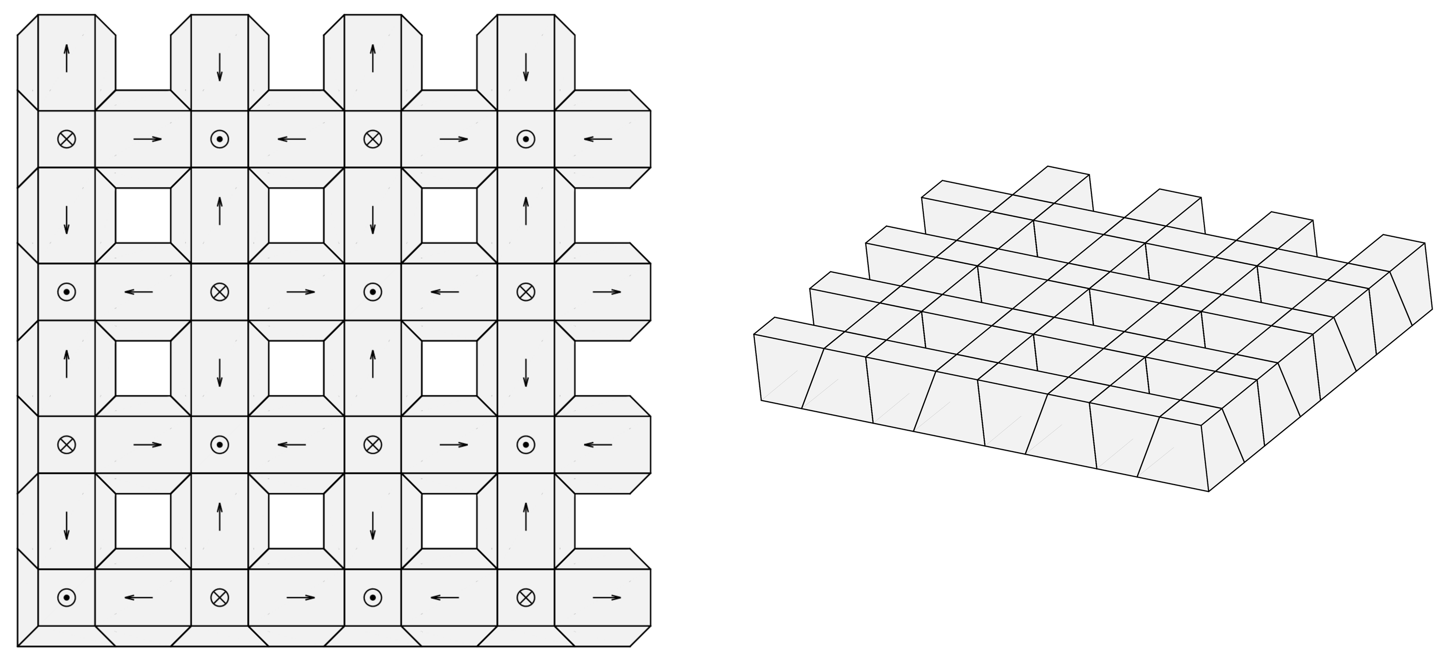

Figure 3: A planar Halbach array using pyramid and tetrahedral frustum magnets.

This array was defined for frusta with an average volume of 1 unit^3 and the magnetic field in the z-direction calculated 0.1 units above the array, shown in Figure 4.

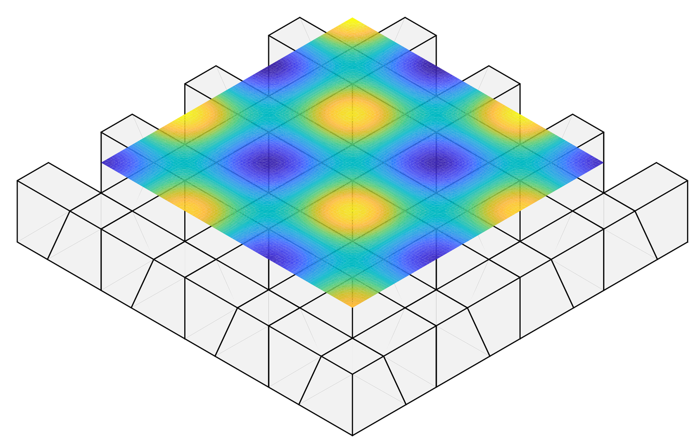

Figure 4: The magnetic field in the z-direction above the Halbach array in Figure 3.

In a planar motor, force ripple can be reduced by creating a sinusoidal field shape and moving force can be increased by creating a field with a large amplitude. The similarity between the field produced by a planar array and a sinusoid can be quantified using a least squares method, giving a coefficient of determination r^2 and an equivalent sinusoid amplitude A. Thus, a desirable field for a planar motor has a large coefficient of determination, leading to reduced force ripple, and a large amplitude, leading to increased moving force.

The cost function to be maximised was defined as $C = Ar^2$. Constraining magnet volume and array size, an optimisation routine was run, allowing the wall angle θ and magnet height h to vary while maximising the cost function, giving the optimal frustum geometry. This was repeated for cuboidal magnets by constraining the wall angle to $\theta = 90°$, giving the optimal cuboidal geometry.

The obtained results showed that under most conditions, the improvement in C using optimal frustum magnets rather than optimal cuboidal magnets was less than one percent.

Conclusion

This research has investigated differences in the magnetic field produced by frustum and cuboidal permanent magnets in a planar Halbach array. A cost function was defined, quantifying the similarity of the field to a sinusoid and the strength of the field. This cost function was maximised for both frustum and cuboidal magnet configurations to obtain the optimal magnet geometry for each configuration. The results showed that the optimal frustum geometry had no significant improvement over the optimal cuboid geometry when maximising the cost function.

References

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